unequal size quickly separate. Clearly, then, drops of equal size are more likely to be brought together by fortuitous disturbances—gusts, turbulences, and the like—than are drops of unequal size.

Furthermore, as explained by Schmidt,[2] two drops falling side by side are slowly pushed together, just as passing boats are driven toward each other, with a force that depends in a known way (the full solution involves considerable mathematics) upon the velocity of fall, the size of the drops, and their distance apart.

Hence, because drops of the same size fall with the same speed they are more likely to be brought together through fortuitous disturbances, and through dynamical action of the atmospheric current past them (resulting from their fall through the air), than are drops of unequal size and consequent different velocity.

Finally, then, given drops of the initial mass m at the base of the cloud, the rain drops at the surface of the earth will tend to group themselves in the mass ratios

$$m : 2m : 4m : 8m : \ . \ . \ . \ .$$

just as observation has shown them actually to be grouped.

[2] *Met. Zeit.*, 25, p. 496, 1908.

551.54 : 551.578.1

FALLING RAIN AND ATMOSPHERIC PRESSURE.

By W. J. HUMPHREYS.

[Weather Bureau, Washington, D. C., Sept. 1, 1921.]

It is well known that a spray of water falling down a vertical pipe increases the air pressure at the bottom of that pipe. In fact for more than 2,000 years this simple device in some form has held its own in the production of blasts for smelting and other purposes.

For simplicity assume the drops to be evenly distributed throughout the tube and falling with a uniform velocity, a condition that well may be closely approached. Under such conditions the viscous drag of each drop on the air within the tube is equal exactly to its own weight. Hence when the blast is shut off, the pressure per unit area at the bottom of the tube is $(w-a)/s$, in which w is the weight of all the water in the column of spray, a the weight of the air displaced by this spray, and s the cross section of the tube. Clearly, then, with plenty of water and a high pipe almost any increase in pressure may be obtained.

Now, at the time of a heavy shower the column is half a mile high or more, and the water in it at any given instant sufficient, perhaps, to produce a rainfall an eighth of an inch deep. But the process of falling of these drops does *not* increase the barometric pressure, as one might infer from the action of the spray trompe that it would.

Before the rain begins the barometer measures the gravity pressure of all the atmosphere, including the water vapor, above it. Let now some of the vapor be condensed into droplets. So long as these are falling with uniform velocity their pull down on the atmosphere is exactly equal to their weight, and hence this pull can not increase the pressure of the air on the surface of the earth below them. When two or more droplets unite the weight of the resulting drop is the sum of the weights of the several separate parts that so united, while its drag on the air at first is much less than the sum of the initial drags. Hence, by the amount of this decrease the pressure on the surface of the earth is also decreased. But the velocity of fall of the enlarged drop is immediately accelerated, and the acceleration continues until the drag becomes again equal to the weight and hence the surface pressure brought back to its previous value. As the drops reach the earth the total air pressure is correspondingly reduced, and slight readjustments occur in the distribution of the atmosphere which it would be tedious to attempt to follow in detail.

In the process, therefore, of condensation and rainfall, while air flows into the partial vacuum caused by the condensing of the water vapor, thus causing slight pressure changes, and while the total pressure of the atmosphere is reduced by the weight of the water reaching the surface, and while immeasurably minute decreases in pressure temporarily follow the union of smaller drops into larger, the viscous drag of the rain on the air does not raise the surface pressure above its original value, as occurs at the bottom of a pipe in which spray is falling. In the case of rain there is either weight (while vapor) or equivalent drag (of the drops) on the atmosphere, so that transfer from the one to the other can not affect the surface pressure. In the case of the spray, on the other hand, the weight is not on the air, but on the feed tube, while the drag of the falling drops is on the air within the vertical pipe. In this case the transfer is not from weight on the air to drag on the air (an equal gain and loss) but from weight on an independent support to drag on the air, a net gain in respect to the atmospheric pressure.

DO THE GREAT LAKES DIMINISH RAINFALL IN THE CROP-GROWING SEASON?

551.578.1 (285 : 71 : 73)

By CYRUS H. ESHLEMAN, Meteorologist.

[Weather Bureau, Ludington, Mich., Sept. 19, 1921.]

SYNOPSIS.

During the severe drought in the early summer months of 1921, at Ludington, Mich., showers frequently seemed to avoid the shore of Lake Michigan. This led the writer to investigate the question whether or not the Lake actually causes a diminution in the normal amounts. The records show an area of maximum fall in the interior of extreme southern Michigan, in May, June, and July. In August and September the area is absent. Less rainfall occurs along the eastern than the western shore of Lake Michigan, and there is a maximum area in the interior of Wisconsin. Apparently the Lakes do cause some diminution. The probable cause is the Lake breezes during the middle of the day and the afternoon, strongest in May, June, and July, which promote circulation and have a lateral movement that prevents the ascending currents needed for local thunderstorms. In general, however, the monthly amounts are sufficient for agricultural interests.

Severe drought conditions prevailed during the early and middle crop-growing months of 1921, at Ludington, Mich., and in a number of counties of the vicinity, along the eastern shore of Lake Michigan. Conditions were similar in many other sections of the United States, but as viewed locally, it appeared frequent rains were falling not far away. This was due partly to mere chance, several storm paths having been just to the north or south, but none for a number of weeks over the strip covering Ludington. However, in some degree, it seemed local causes were operating. Several good rains occurred just across the Lake to the west. Frequently clouds appeared in the west as if to produce rain, but were dissipated without doing so. Frequently local thunderstorms appeared to form just east of the station, and thunder was heard and showers were reported. On four successive days in one case, heavy clouds were observed in the middle of the day in the east, while overhead, and in the west, north, and south the sky was cloudless.

The writer has been stationed along this shore of Lake Michigan about 11 years, approximately half of the time at Grand Haven and the other half at Ludington. He had previously thought that the Lake does not materially diminish the amount of rainfall; that while it might do so in some instances, these are compensated by opposite effects when the winds in the same month are from the other directions. He had often seen thunderstorms come in from the Lake and had not noticed that they were weakened or dissipated. It was clearly recognized that in months when the Lake is warmer than the land, precipitation is usually slow to begin with offshore winds, the reason being that the wind is warmed as it approaches the Lake; but it was thought, as stated above, that the effect is largely neutralized by opposite influences when the winds are reversed.

But in the 1921 season, the numerous instances when showers appeared to be influenced by the Lake, led the writer to begin an inquiry as to whether, in the long run, during any of the crop-growing months the rainfall is actually diminished. There has been little study of the result of the differences in periods, and the normals as used probably show quite accurately the amounts as caught by the gages. Whether the catch of the gages is affected by altitude or wind velocity, or other causes, will be considered after the examination of the data.

In figure 1 is shown the total for the five-month period May to September, inclusive; the total for May, June, and July; and the total for August and September.

It is readily seen that for the three months, May, June, and July, there is an area of maximum rainfall in the interior of extreme southern Michigan, whence there is a decrease to the east, west, and north, though the decrease is comparatively slow northeastward toward Saginaw Bay. There is perhaps a secondary maximum to the east of Ludington. In August and September, according to figure 1, the maximum area in the south is absent.

The Michigan distribution from May to September and May, June, and July are embraced in a larger area covering Michigan, Wisconsin, and the Lakes.

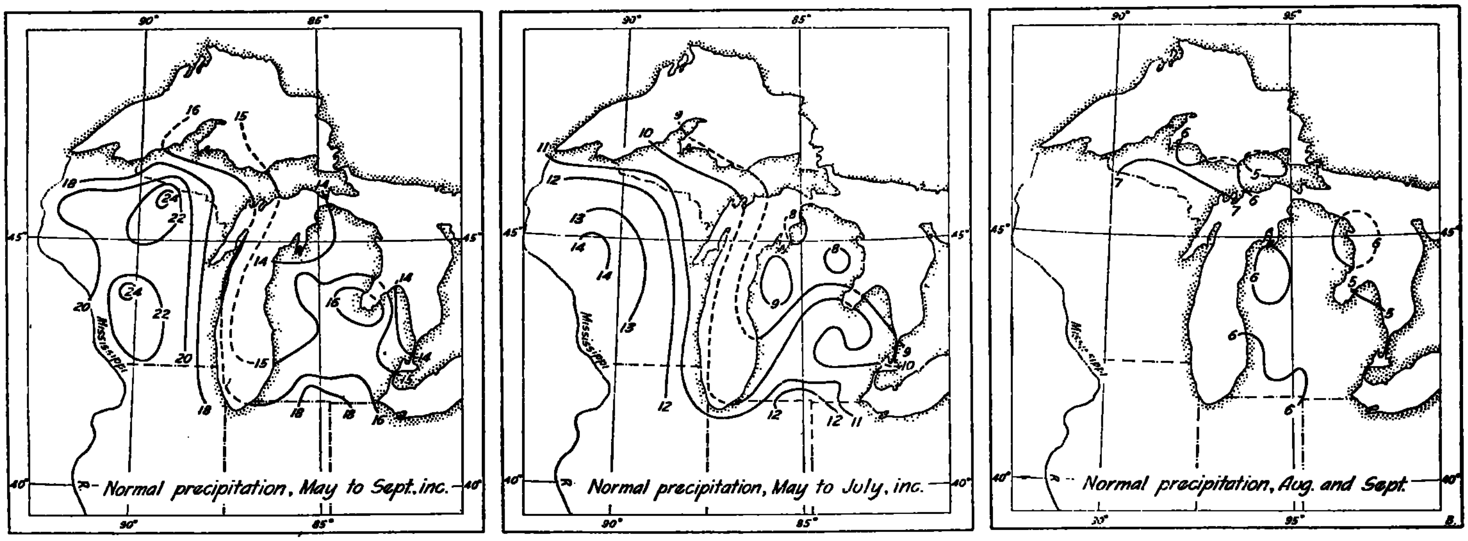

FIG. 1.—Distribution of precipitation for various periods for Michigan, Wisconsin and the Lakes.

winter precipitation, since for agricultural interests the amounts then are not important, and since, also, there are many complications connected with snowfall measurements that make the problem perplexing, if not at present insoluble.

Several years ago Mr. Eric R. Miller, of the Madison, Wis., station, studied the effects of the Lakes on the climate of Wisconsin. The results are given in a paper read at the second Pan-American Congress, 1915–1916, and published in the *Proceedings*, Volume II, section II, page 189. One of the conclusions drawn was that decidedly less rainfall occurs near the Lakes in summer, the excess in the interior of the State for the period April to September, inclusive, being 12 inches, or 86 per cent of the amount falling along the Lakes.

In order to learn the distribution in Michigan the present writer has charted the normal amounts as given in the monthly climatological data for all the regular and cooperative stations. The periods of observation range from 20 to 50 years or more. In general, the periods are longest for the shore stations, owing to the fact that most of the regular stations are there and were earliest established. But there are numerous long-period cooperative records in the interior of the middle and southern portions of the lower peninsula. In the interior of the northern portion and in the interior of the upper peninsula the records are comparatively brief and meager. But there appear to be no radical inconsistencies as a

A comparison of the normals for the stations immediately along the west and east shores of Lake Michigan is interesting and significant.

Tables 1 and 2 give the figures for six stations along the west shore and six in the same latitude along the east shore.

TABLE 1.—*Comparison of normal rainfall along west and east shores of Lake Michigan for May, June, and July.*

Wisconsin stations:	Inches.	Michigan stations:	Inches.
Green Bay	10.63	Frankfort	8.67
Manitowoc	10.80	Manistee	8.85
Sheboygan	10.33	Ludington	8.84
Port Washington	10.95	Hart	9.11
Milwaukee	10.11	Muskegon	8.56
Racine	10.50	Grand Haven	8.43
Total	63.32	Total	52.46

Seventeen per cent less along east shore.

TABLE 2.—*Comparison for August and September.*

Wisconsin stations:	Inches.	Michigan stations:	Inches.
Green Bay	6.07	Frankfort	5.38
Manitowoc	5.10	Manistee	5.52
Sheboygan	5.99	Ludington	5.35
Port Washington	6.08	Hart	5.70
Milwaukee	5.80	Muskegon	5.49
Racine	6.67	Grand Haven	5.76
Total	35.71	Total	33.20

Seven per cent less along east shore.

Let us now inquire briefly as to the causes of the distribution shown by these figures and tables.

Part of the northward decrease through the lower peninsula of Michigan may be due to increasing distance from the Atlantic Ocean and the Gulf of Mexico. A fraction of the excess in the southern interior of the State and of the slight excess to the east of Ludington may be due to the altitude, which is 300 feet or more above that along the Lakes; but if this influence were important it should be apparent also in August and September. There may be a percentage of error due to the stronger wind velocities at the shore stations, which cause eddies at the mouth of the rain-gage and thus reduce the catch; but if this error were large it should operate no less in August and September, when the average daily velocities are practically the same. Other sources of error and other causes of the conditions might be suggested. Nevertheless, the evidence seems strong that somewhat less rain falls along the Lakes and that the Lakes are in some degree the cause.

There is at least one unquestionable fact with which to begin. Cumulus clouds are rare along the eastern shore of the Lake. I refer to the type common during the middle of the day in summer at practically all inland stations. This indicates an absence of the ascending air currents which cause the cumulus and which in a more pronounced development lead to thunderstorms. The absence of the ascending currents is evidently due to the Lake breezes, which prevail during that time of the day, and, coming in to the shore, give the wind a strong lateral direction. This constant circulation of relatively cool air prevents the stagnant conditions and inequalities of air temperatures that are necessary for thunderstorm development. And, since thunderstorms usually travel in an easterly direction, a diminished frequency would be felt to some distance inland. This circulation due to Lake breezes may in some degree cover the whole northern end of the lower peninsula and thus prevent the greater rainfall that occurs in the interior of the southern portion which is less surrounded by water. The fact that more rainfall occurs along the west shore in Wisconsin may be accounted for by the statement that thunderstorms originating far inland to the westward would proceed almost, if not entirely, to the Lake before encountering the unfavorable tendencies. The advantage for interior counties in Michigan disappears in August and September, it may be stated, because the Lakes have then become warmer and the breezes weaker.

Another proof that some influence operates against daytime rainfall is the fact that more than 50 per cent in the summer season falls in the night, from 7 p. m. to 7 a. m.[1] The writer has computed the amounts at Ludington for the past nine years since the regular observing station was established, and finds that 61 per cent of the rainfall from May to September, inclusive, has occurred between 7 p. m. and 7 a. m., leaving only 39 per cent for the other 12 hours. However, it is possible that conditions along the Lake increase the night rainfall, thus in part making up the deficiency.

CONCLUSION.

Recognizing the possibilities of error and disclaiming any desire to dogmatize, the writer is nevertheless inclined to advance the view that the Lakes diminish the daytime rainfall along the Lake in early summer. This influence is due in part at least to the Lake breezes, which are relatively cool and give a lateral direction to the wind and prevent the stagnant conditions and inequalities of heat that favor the development of thunderstorms. The diminution may in part be compensated by increased rainfall at night, and in general the monthly totals are sufficient for agricultural interests.

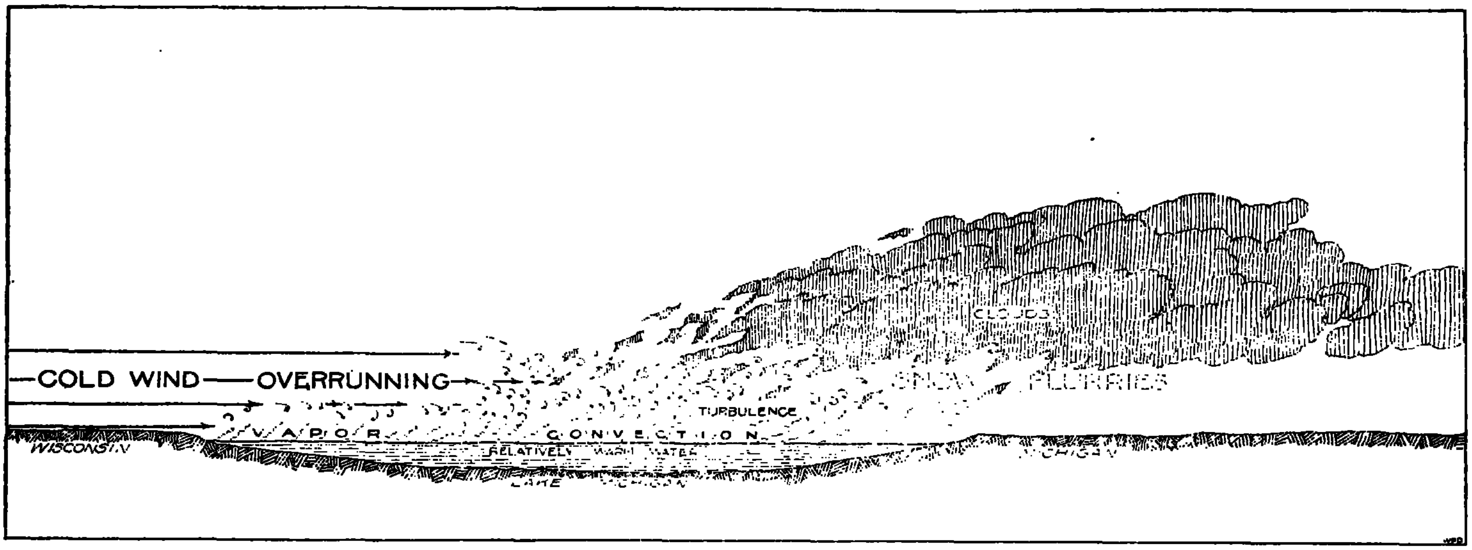

FIG. 1.—Formation of clouds and fog over Lake Michigan.

SNOW FLURRIES ALONG THE EASTERN SHORE OF LAKE MICHIGAN.

The familiar phenomenon of snow flurries with westerly winds, especially during the early part of winter, at Grand Haven and Ludington along the eastern shore of Lake Michigan, and possibly as far inland as Grand Rapids, while clear weather prevails at Chicago, Milwaukee, and Green Bay on the western shore, prompted the writer to ascertain, if possible, how far back over Lake Michigan these snow flurries extend, as well as the cause of the cloudiness and snowfall. It was thought that the vessel masters of the Pere Marquette car ferries plying between Ludington, Mich., and Milwaukee and Manitowoc, Wis., should be able to furnish quite definite information as to the extent of these flurries over the lake. Accordingly, request was made of the official in

[1] Humphreys, W. J.: On the differences between summer daytime and night-time precipitation in the United States. MO. WEATHER REV., June, 1921, 49: 350-351.

charge at Milwaukee to obtain, if possible, the desired information. Replies to his letter of inquiry were received from Masters Bahle, Robertson, and Van Dyke, that of Master Bahle [1] being given below:

> With the wind west and the weather clear we may have vapor or steam, as we call it, part way or all the way across the lake. All depends on the difference in the temperature of the water and the air. During the early part of winter, say in December, when the water is not the coldest, the weather will moderate as we reach the east shore or as we near the east shore and this will cause the steam (fog) to rise off the water entirely in clouds and then snow may fall. I have seen this anywhere from the middle of the lake to the east shore. Later in the winter when the water becomes real cold and the air temperature say about 15° below zero on the west shore, the steam (fog) may reach the east shore and snow there also, the snow not extending out in the lake more than 2 or 3 miles. In other words, it does not snow when the steam (fog) makes. It starts to snow where the steam (fog) stops making and starts to rise in clouds entirely away from the water.

Masters Robertson and Van Dyke both wrote that steam or fog rising on the western shore of the lake means snow on the eastern shore, and that these flurries extend back 10 to 20 miles from the eastern shore, as a rule.

The cold air from the west reaches Lake Michigan with a temperature considerably below freezing and sweeps out over the lake, the water of which has a temperature of nearly 40° early in December and approximately 32° during January and February. It appears, therefore, that there is a layer of warmer air immediately over the lake under these conditions, being necessarily quite shallow along the western shore and increasing in depth toward the east, and that convectional currents and turbulence set in, manifesting themselves in the form of vapor near the western shore, in the formation of clouds farther out in the lake and, eventually, precipitation in the form of snow flurries where convection and turbulence are sufficient to produce it.

The accompanying illustration by Mr. W. P. Day (p. 502) shows graphically the manner in which clouds and precipitation are brought about.—*C. L. Mitchell.*

A SIMPLE FILLING APPARATUS FOR DEFINITE INFLATION OF PILOT BALLOONS.

551.508.8

By R. C. LANE, Observer.

[U. S. Weather Bureau, Washington, D. C., Aug. 30, 1921.]

SYNOPSIS.

Indefinite and definite inflation of pilot balloons for aerological observations.—The rate of ascent at which pilot balloons rise in the free air is determined from the formula

$$V=72\left(\frac{l}{L^{\frac{1}{3}}}\right)^{\frac{5}{8}},$$

where V is the rate of ascent in meters per minute, l is the free lift in grams of the inflated balloon, and L is the total lift of the confined gas. The character of the formula is such that it is impracticable for the average observer to solve for either l or L, with respect to any given or desired value of V. Up to this time inflation can be defined as *indefinite*, wherein the rate of ascent has been dependent upon the weight and free lift of the inflated balloon, and the magnitude of the rate could not be controlled by the observer except within narrow limits. By means of the apparatus herein described the author makes a convenient and valuable transposition, wherein the free lift of the balloon for any desired rate of ascent is dependent upon the weight of the balloon and the rate of ascent selected. This provides a method of *definite* inflation wherein the observer is able to select any rate of ascent suitable to the fancy or to the current meteorological conditions, and inflate the balloon accordingly. The process of inflation is thereby resolved to the equivalent mechanical operation of the method, earlier used.

Since the earlier stages of pilot balloon observation work, the need of some efficient apparatus for the inflation of balloons to a particular rate of ascent has been generally felt, and this need has increased with the rapid development of observation work. The apparatus here disclosed has been devised after considerable study of various methods and after much experimental work. The simplicity of the arrangement and the purely mechanical manipulation of the apparatus in practice, with the small amount of machine work necessary in construction, should tend toward the general use of such an apparatus in observations with pilot balloons.

At present, balloons, when inflated with hydrogen, are assumed to rise with a nearly constant rate of ascent. In the United States, the rate v, at which they are assumed to ascend, is computed by a formula which takes into account the weight w, in grams, of a rubber balloon expelled of air; the free lift l, or the mass in grams that the inflated balloon will just sustain; the total lift L, $(w + l)$, or the entire mass in grams that the confined gas will support; and a constant 72, determined by a careful study of numerous double-theodolite observations. The formula expressing the rate of ascent was devised by the Meteorological Section of the Signal Corps, and is as follows:

$$V=72\left(\frac{l}{L}\right)^{\frac{5}{8}}. \tag{1}$$

Pilot balloons are inflated according to either of two methods. One may be known as indefinite inflation, and the other as definite inflation. By the method of indefinite inflation the balloon is first weighed, then inflated with gas to near some particular diameter, the free lift of the inflated balloon measured, and the rate of ascent computed from these data by the formula. The resulting rate of ascent may be any odd value. By the method of definite inflation, some convenient rate of ascent is determined, the balloon is then weighed, the amount of free lift necessary for that particular rate of ascent and weight is then determined, and the balloon inflated accordingly.

Inflation by the definite method is superior to the indefinite since it enables one to inflate to any desired rate of ascent. In view of this fact, a rate of ascent of 200 m./min. or any other rate in which the successive multiples end in one or more zeros, will materially increase the ease, speed, and accuracy of computation in determining the horizontal distance of the balloon from the observation point. Whether the computation be made by slide rule or by graphical means, the above statement is equally true. As an illustration, suppose the altitude of a balloon at the end of some particular minute when inflated by the indefinite method is 3151 meters, and by definite inflation we have an altitude of 3300 meters for the corresponding minute. The number 3300 can be set more quickly and accurately on the slide rule than can the number 3151. Experience has proved that the definite inflation method will not only insure accuracy and speed, but will truly permit a higher quality of work in general.

Definite inflation is more difficult to attain than indefinite inflation and is practically impossible without the aid of some specially designed apparatus. The character of the formula by which the rate of ascent is computed,

[1] The following interpretation is put upon the letter reproduced above: In December when the water is warmer than the overlying air surface air coming from the west becomes warmer as it passes over the lake and gains distance toward the east until finally it reaches a point over the lake when the contrast in temperature between air and water is not sufficient to form fog. By this time, however, vertical convection has carried the moisture of the fog high enough to be condensed as snow and this is probably the explanation of the statement—it does not snow when fog makes; it starts to snow when the fog stops making and starts to rise in clouds.

Evidently there are times also when the fog extends from shore to shore; at these times there may be snow on the east shore.—EDITOR.